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ELECTRONIC MEASUREMENTS OF SNOW SAMPLE WETNESS

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ABSTRACT

Several electronic methods described here can readily measure the wetness of snow. The first method is based on the change in capacitance of a snow sample before and after freezing, which is directly related to the amount of moisture initially present. The second is based on the losses in a resonating electrical circuit (or Q) and depends on the amount of liquid-phase water in the snow being measured. Field tests for both systems have been made to demonstrate the principles. Preliminary calibration curves are presented. A field unit is described that can obtain in situ values for snow wetness.

The amount of liquid-phase water in snow ("wetness") is an important factor in runoff prediction and water resource management. Various systems (calorimeters, centrifuges, etc.) are available for measuring wetness. Although each method has its proponents, none has been uniformly accepted. This paper describes two electrical methods for measuring the wetness of snow: one based on measuring the capacitance of a sample before and after freezing it and the other on in situ measurement of the dielectric loss of a sample in a high-frequency field.

The capacitance of a given test unit is proportional to the net dielectric constant of the medium between the electrodes. For dry snow – a mixture of air and ice – the factors that affect the net dielectric constant include the individual dielectric constants of the air and the ice, the relative proportions of each, the temperature, the oscillation frequency at which the measurements are made, and the "form factor" (also called "formzahl"), which depends on the shapes and orientations of the crystal. For wet snow, the situation is more complicated, even though the temperature is not a variable, being essentially 0°C because of the effect of melting. The dielectric constant of pure water at 0°C is 87.7, but when the water is in contact with ice crystals, intramolecular forces can affect the dipole moment of the water. Nevertheless, the dielectric constant of snow is greatly increased by the presence of liquid-phase water, and this fact has been the basis for previous methods of determining snow wetness by Gerdel (1954) and Ambach and Howorka (1966) from capacitance measurements. Gerdel's equation for the dielectric constant of a unit volume of wet snow is

$$k_s = k_i V_i + k_w V_w + k_a V_a \tag{1}$$

The individual dielectric constants and volumes of snow, ice, water, and air are represented, respectively, by k and V with subscripts s, i, w, and a.

Gerdel states: "The capacitance meter readily detects the presence of water in the snow in amounts of a fraction of one per cent. It is not possible to produce a uniform artificial mixture of snow and water with a known low free water content to serve as a standard and since no satisfactory precision method for measuring the liquid water present in a natural snow cover is available it has not been possible to calibrate the meter for all snow types."

Gerdel used his capacitance meter to measure the relative amounts of water in a given snowpack under various wetness conditions.

Ambach and Howorka give equations for the dielectric constant as a function of snowdensity and wetness:

$$k_S(\text{dry}) = 1 + 2.2g \quad (g \text{ in gm/cm}^3) \tag{2}$$

$$k_S(\text{wet}) = 1 + 2.22g + 0.236W \tag{3}$$

The volume percent of liquid-phase water is represented by W and k_S represents the dielectric constant of snow. However, the effect of the "form factor" of the snow is not included in equations (2) and (3).

The method proposed here to obtain the wetness of snow involves measurements of capacitance before and after a sample is frozen. The unit can consist of two electrodes separated by dielectric spacers that also serve as side walls. All four edges that enter the snow are sharpened. Since the effect of the form factor on the capacitance is present in both measurements, in the subtraction process the net contribution vanishes. In other words, only the capacitance attributable to the original wetness is manifested by the value before freezing minus the value after freezing. After the unit has been completely inserted into the snow and is uniformly filled, it is carefully removed and its capacitance measured. The unit is then placed in a chamber maintained at a temperature below freezing (e.g., at −20°C) to freeze the snow by heat conduction through the electrodes. A convenient, portable, freezing apparatus can consist of an insulated box with dry ice (solid carbon dioxide). After it is completely frozen, the test unit is removed and its capacitance remeasured. Although knowledge of the density is not required, it can be obtained for the sample by weighing the snow since the volume is known.

The information thus obtained includes the density of the snow, the dielectric constant of the snow plus liquid-phase water, and the dielectric constant of the snow plus frozen-out water. The method was tested during the spring of 1973 at the Central Sierra Snow Laboratory (CSSL), Soda Springs, California. For example, a snow bank was sprayed with 0° water and allowed to drain for about an hour. The snow was then placed between electrodes separated by 1 inch (2.54 cm), with dimensions of 12 inches × 16 inches (30.5 cm × 40.7 cm), having a capacitance of 80 micro-micro-farads (mmf) when empty. With the wet snow present, the capacitance was 193 mmf. After freezing in a dry-ice box, the snow reached a temperature of about −20°C, and the corresponding capacitance was 136 mmf. From these data, the dielectric constant for the wet snow was calculated to be 2.41, for the dry snow it was 1.70, leaving a contribution of 0.71 for the dielectric constant of the liquid-phase water initially present in the snow. The density of the snow was 0.42 gm/cm³. To obtain the volume percent of liquid-phase water initially present in the snow, suitable calibration curves relating the wetness to the increase in dielectric constant are necessary. (This research is planned for the winter of 1973-74.)

Alternative methods of freezing the snow sample were also tested, such as circulating cold air through the snow sample with perforated electrodes so that the dielectric constant could be measured during the freezing process. An ordinary household vacuum cleaner provided sufficient air flow through a snow sample in the form of a cylinder having a diameter of 10 inches (25.4 cm) and a height of 1 inch (2.54 cm). The air was passed through a tube containing dry ice. However, the heat-conduction method of freezing appears to be more convenient and simpler.

Some of the problems encountered in producing dielectric constant versus wetness curves were explored at CSSL. A walk-in refrigerated room was maintained at 0°C, where all weighing and electrical measurements were made. A capacitor was employed having aluminum electrodes 13 inches × 13 inches (33.0 cm × 33.0 cm) separated by a Plexiglas frame 1 inch (2.54 cm) high and 0.5 inch (1.27 cm) thick, giving a working volume of 12 inches × 12 inches × 1 inch (30.5 cm × 30.5 cm × 2.54 cm or

2.36×10^3 cm^3). The empty weight of the unit was 1465 gm, and its capacitance was 75 mmf. Dry snow at −3.5°C was placed in the unit; it weighed 1267 gm, yielding a dry density of 0.536. The capacitance of the unit with the dry snow was 104 mmf, for which the dielectric constant was 1.39.

Next the snow was removed from the unit and placed in a mixing bowl, where 0°C water was sprayed on it. After it was thoroughly mixed by insulated gloved hands, the snow was replaced in the capacitance unit and reweighed. The increase in weight in grams, due to the water added, multiplied by 100 and divided by the volume of 2.36×10^3 cm^3 represents the volume percent of water added. The capacitance of the unit with wet snow present minus the capacitance of the unit with dry snow present divided by the capacitance of the empty unit represents the increase in dielectric constant produced by the liquid-phase water in the snow. Such data were obtained in successive steps (water added, mixed, weighed, and capacitance measured) and are shown in Figure 1 where the volume percent of water added is the abscissa and the increase in dielectric constant is the ordinate. The measurement frequency was 3.84×10^6 Hz. The measured capacitance values have an uncertainty of about ±1 mmf, which is equivalent to ±0.02 in the dielectric constant.

The experimental data include the effect of the initial temperature of the snow (−3.5°C). The specific heat of ice is 0.5 Cal/gm/°C. With the density of 0.54 gm/cm^3, the amount of heat to bring the snow to 0°C is 0.95 Cal/cm^3. The heat of fusion of pure water is about 80 Cal/gm. To heat the snow to 0°C requires about one volume percent of water freezing to ice. This implies that, for accurate results, the snow should be very close to 0°C initially.

Other effects to be considered include unmeasured heat input to the snow, such as the effect of heat conduction from the gloved hands, the work of mixing, human body radiation, breath exhaling, etc. These have an opposite effect to that discussed in the preceding paragraph. For future calibrations using the mixing method, a "control" sample of snow will be subjected to the same operations and environment as the test sample, except no water will be added.

If it is assumed that Figure 1 can be applied to the snowbank example previously described, for which a change in the dielectric constant of 0.81 was measured upon freezing the sample, the wetness value of 5.5 volume percent is obtained; for a density of 0.42 gm/cm^3, this corresponds to a wetness of 13 percent by weight (i.e., grams liquid water/grams dry snow multiplied by 100).

So far, the discussion of calibration has included only the mixing of dry snow with known amounts of water. Clearly, comparisons should be made with measurements using other systems, such as calorimeters, centrifuges, etc.

A more elegant method of calibration (not yet tested) could be based on the use of "heavy water" (D_2O) in a refrigerated room. With a large volume of snow at slightly below freezing (about −0.1°C), a known amount of heavy water would be sprayed so that the upper portion of the snow would become saturated. After suitable time intervals, samples from various layers of the snow would be selected, and capacitance values measured before and after freezing. These changes in dielectric constant would then be related to the heavy water present in each sample, using a mass spectrometer or other nuclear abundance instrument to obtain the relative amounts (i.e., grams D_2O/grams H_2O). The homogeneity of the D_2O distribution may be similarly evaluated by dividing the snow sample from the test unit into small portions and measuring them on the nuclear instrument.

Additional moisture measurements have been performed using foam rubber as the medium to which water is added to determine the reproducibility and precision of results. No freezing or melting considerations are involved. Results are shown in

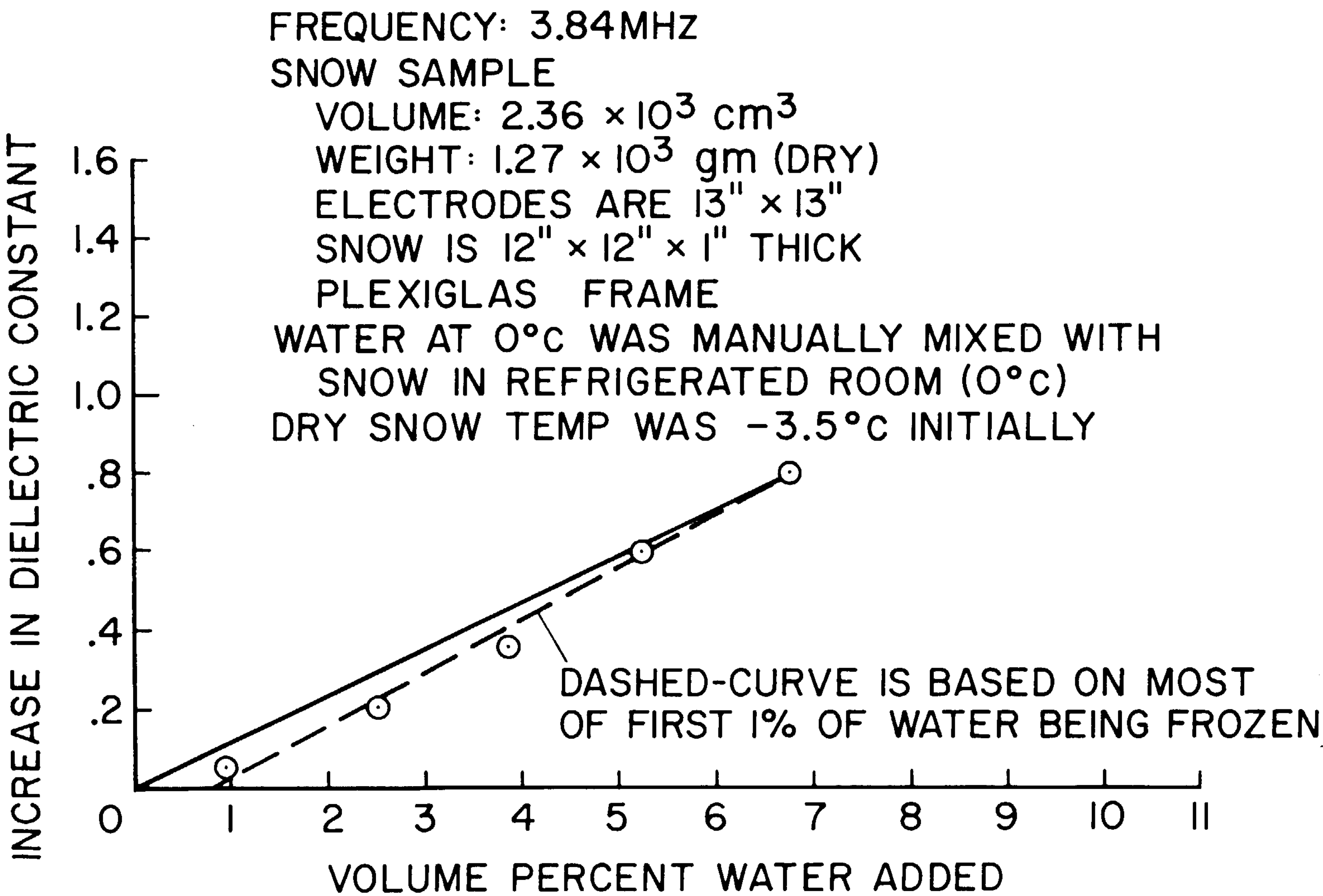

Figure 1. Increase in the dielectric constant of snow produced by water added.

Figure 2, where the volume percent of water added is the abscissa and the increase in dielectric constant is the ordinate. The foam rubber had a dry density of only 0.0180 gm/cm^3 and a dielectric constant of 1.082. The dimensions of the foam rubber and the aluminum electrodes were 13 inches × 13 inches (33.0 cm × 33.0 cm) with a height of 1 inch (2.54 cm), giving a volume of 2.73×10^3 cm^3. The frequency used was 3.68×10^6 Hz. Runs were made on successive days, as indicated by the X, O, and Δ points.

Figures 1 and 2 show that a given volume percent of water (e.g., 5%) added to foam rubber did not increase the dielectric constant much more than when the same volume percent of water was added to snow (0.72 and 0.60, respectively). Because the density of foam rubber (0.018) was much less than the density of snow (0.42) for the samples tested, one might have expected that the moisture in the foam rubber would exhibit more nearly its pure-state dielectric constant value of 87.7 instead of the effective value of only about 15.

It is concluded from the preliminary calibration curve for snow and the comparison curves for foam rubber that the wetness of snow can be measured conveniently and accurately with the system based on the capacitance change caused by freezing the snow sample.

IN SITU MEASUREMENTS BASED ON "QUALITY FACTOR"

A disadvantage of sampling methods for measuring snow wetness is that a pit must be dug to obtain the samples; this is difficult, time-consuming, and expensive for routine data acquisition. For this reason, an alternative method based on "quality factor" (hereafter termed Q) measurement is described below, which could be used in conjunction with the customary snow-tube measurements on established snow courses. The Q as well as the capacitance (hereafter termed C) of the snow can be measured with the same set of electrodes. The term "capacitance unit" will be used to describe the electrodes plus an intervening dielectric, even though the unit will be used to measure the Q.

Because the cylindrical hole left by the snow tube is "available at no additional cost," we have designed a cylindrical capacitance unit that can be attached to a snow tube and inserted into the snow. The snow tube itself acts as one electrode, having a diameter of 2 inches (5.08 cm), and is surrounded by a coaxial sleeve acting as the other electrode 4 inches (10.2 cm) in diameter and 4 inches (10.2 cm) long. As this cylindrical capacitor is lowered into the snow, measurements are made at each desired depth; the sampling is done in situ, without extracting the snow sample or freezing it.

Let us now consider the principle of operation for the Q measurement. For a series circuit containing resistance R, inductance L, and capacitance C, when oscillating at a frequency F, $Q = 2\pi FL/R = (2\pi FCR)^{-1}$. A commercially available instrument called a Q-Meter gives readings for Q and C when a capacitance unit is connected to its terminals.

The Q is proportional to the ratio of energy storage to energy dissipation per cycle in the resonating circuit. If the energy dissipation is increased, the Q decreases. When the dielectric between the plates of a capacitor is snow, most of the dissipation in a high-frequency field is produced by the presence of liquid-phase water, thus the Q is high for dry snow and low for wet snow. From a measurement of the Q for a given snow as the dielectric, and with a suitable calibration curve, it appears that the wetness may be determined immediately, without the need for a freezing cycle. (Experimental proof of this hypothesis will be sought during the 1973-74 winter season at CSSL.)

Preliminary measurements of the relationship of the Q to snow wetness have been made in connection with the calibration curve already described, for which known

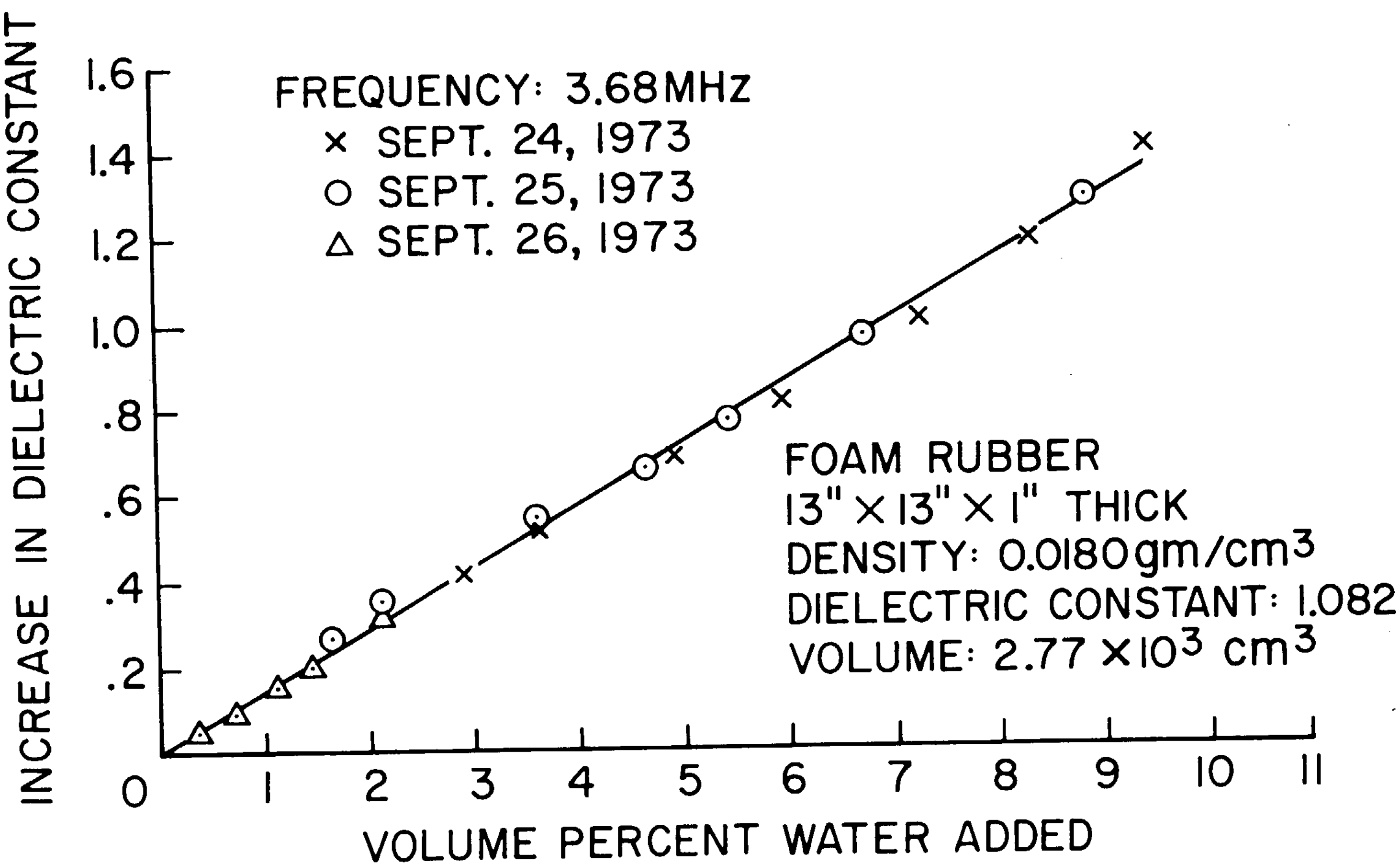

Figure 2. Increase in the dielectric constant of foam rubber produced by water added.

amounts of 0°C water were manually mixed with initially dry snow. Readings for C and Q were taken for each moisture condition; the C dependence has previously been discussed.

In Figure 3, values for Q for dry snow and progressively wetter snow are plotted versus volume percent of water added. Q decreases rapidly as water is added, then it exhibits a more or less uniform rate of decrease in the range of 2 to 8 volume percent of water added.

Because Figure 3 is the only experimental curve to date for snow which shows the dependence of Q on known amounts of wetness, tests were run in the laboratory with foam rubber as the dielectric in a capacitor. As described before, the foam rubber had a dry density of 0.018 gm/cm^3, and a dielectric constant of 1.082. The electrodes and foam rubber were 13 inches X 13 inches (33.0 cm X 33.0 cm) with a height of 1 inch (2.54 cm), giving a volume of 2.77×10^3 cm^3. The frequency used was 3.68×10^6 Hz. The values of Q versus volume percent of water added are shown in Figure 4.

Although the results to date have been quite encouraging, this method of measuring snow wetness must be tested under the normal variety of field conditions before firm conclusions can be drawn. A small amount of conductive impurity in snow, for example, may affect the Q values significantly. However, the use of multiple frequencies for the measurements may provide additional information so that effects produced by liquid-phase water may be identified in a suitably precise and convenient way.

For both methods of wetness measurement described here, a *functional calibration* approach may be useful: the wetness measurements can be correlated with measured runoff data during the ripening and saturated melting episodes.

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Ambach, W., and F. Howorka, 1966. Avalanche activity and free water content of snow at Obergurgl. International Symposium on Scientific Aspects of Snow and Ice Avalanches, pp. 65-72.

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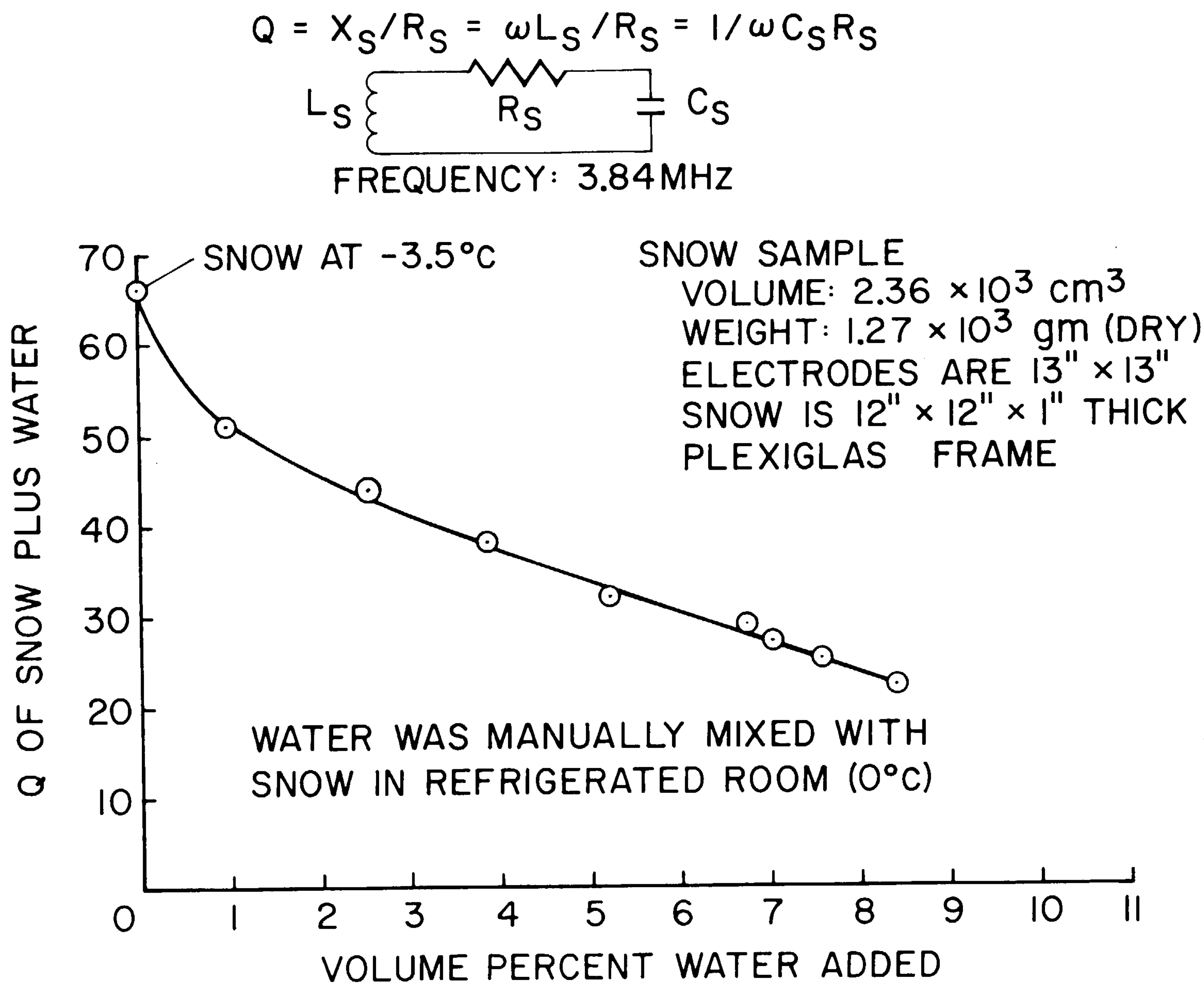

Figure 3. Dependence of Q factor of snow on water added.

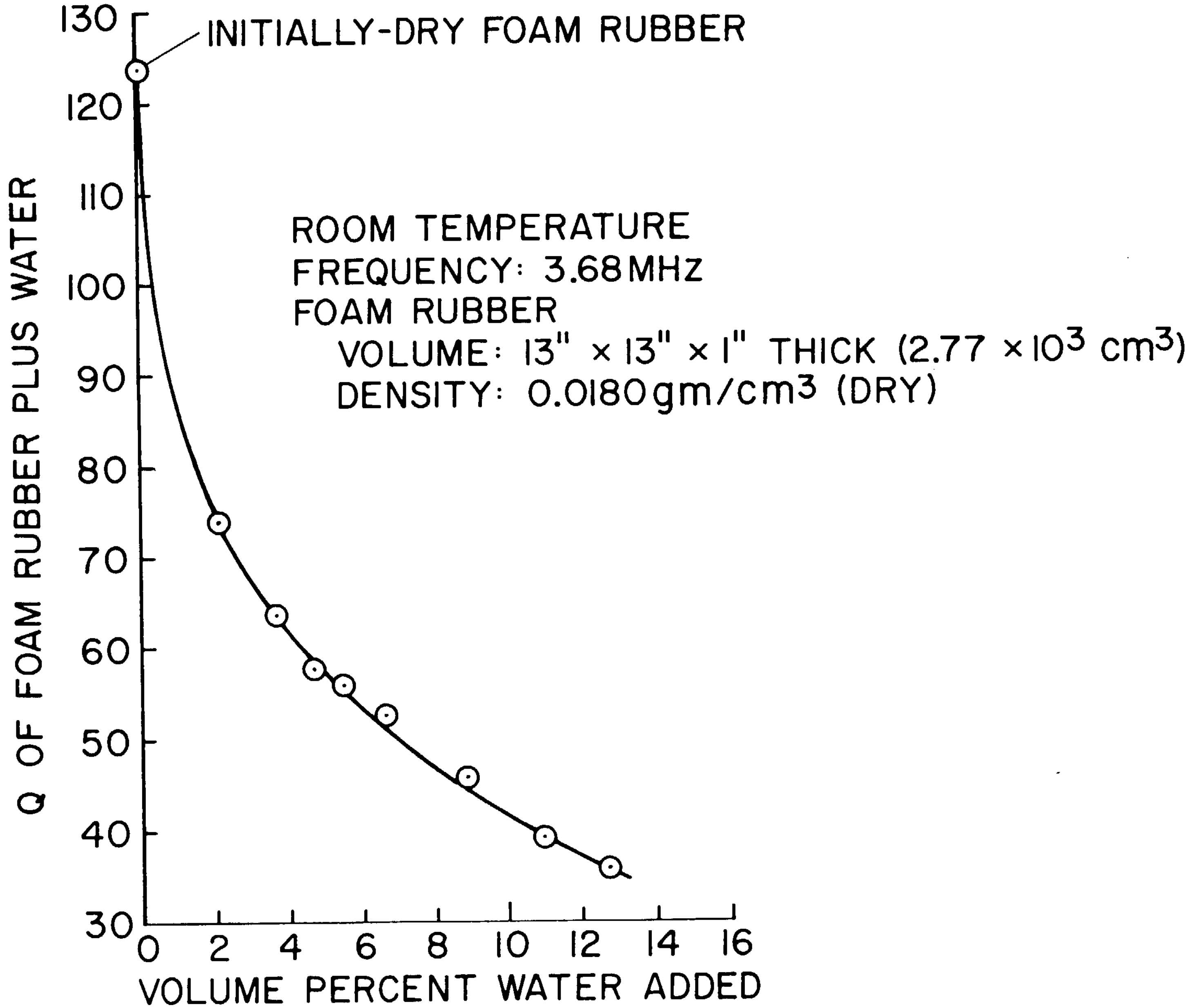

Figure 4. Dependence of Q factor of foam rubber on water added.